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ABSTRACT

This report presents the findings and recommendations of a workshop regarding the effect of international economic and technological changes on graduate student training in the physical sciences and mathematics. Concerns identified about current graduate training include the declining availability of public resources to support training, the narrowness of the skills and knowledge acquired by new doctoral graduates, the increasing emphasis on the research component of graduate experience, and the low level of diversity among graduate students. Recommendations for programs and procedural change regarding these findings are presented. (JPB)

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SUMMARY REPORT

Graduate Education and Postdoctoral Training in the Mathematical and Physical Sciences

Workshop Report

Sponsored by the Directorate for Mathematical and Physical Sciences, National Science Foundation

June 5-6, 1995

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The workshop and these proceedings were supported by the Directorate for Mathematical and Physical Sciences (MPS) of the National Science Foundation (NSF) as a service to the MPS community. However, any opinions, findings, conclusions, or recommendations herein are those of the authors and speakers and do not necessarily reflect the views of the NSF.

Preface

On June 5 and 6, 1995, the Directorate of Mathematical and Physical Sciences (MPS) of the National Science Foundation (NSF) sponsored a workshop on graduate education in the mathematical and physical sciences. Its purpose was to bring together leaders from MPS disciplines to examine the current practices used to prepare young people for careers in science, and to suggest strategies appropriate for the next decade. I am pleased to share with you the findings and recommendations of the workshop.

In many ways, the environment in which today's graduate students and postdoctorals will work is going to be very different from what we knew as young scientists. Federal investments in research will remain constant or decline, at least over the near term. The role of research in industry is changing, especially the contributions expected of the central laboratories of large companies. Added to this must be the realization that the long-sought goal of greater participation by underrepresented groups is being achieved more slowly than we might hope.

In response, we must recognize this new reality and optimize the use of limited human and capital resources. Young scientists should not only be trained to advance intellectual frontiers, but also to meet the changing needs of the universities, companies, and research organizations that will employ them. They should recognize opportunities in their own fields and connections to other disciplines. They should be able to describe the beauty and importance of their work as easily to a group of high school students as to their peers.

John Armstrong, the former director of research at IBM who has given voice to many of these concerns previously, provided skillful and creative leadership both during the meeting and as chair of the steering committee which oversaw its planning. The committee was ably supported by a working group of MPS staff. The workshop also benefited from strong intellectual support by NSF Director Neal Lane and Deputy Director Anne Petersen.

Discussion at the sessions was lively and thoughtful. It was not a "typical" NSF workshop in the sense of being focused on a specific area of scientific research. Yet it followed a model that has been used many times and in which NSF believes strongly: identifying an important issue being discussed in the scientific community and creating a forum that furthers the dialogue.

The workshop serves as part of a broader strategic planning effort within MPS. While the opinions expressed in this report are those of the speakers and invited participants and do not represent NSF policy, I consider them an important step for developing an agenda that will help ensure the health of the mathematical and physical sciences and provide greater opportunities for the next generation of scientists. These recommendations are currently under study within NSF. I invite you to participate in this ongoing dialogue.

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Introduction

The heightened international economic and technological competitiveness of the post-Cold War world and the growing influence of domestic fiscal stringency are forcing the research university community to adjust to a changing environment. In particular, these new forces affect the training of graduate students in the physical sciences and mathematics, and so the Directorate of Mathematical and Physical Sciences (MPS) of the National Science Foundation (NSF) convened a Workshop to examine these forces and to consider issues that impact how MPS carries out its responsibilities as an important supporter of graduate education and research.

Although the infrastructure for training Ph.D.'s in the mathematical and physical sciences in the United States has been extremely successful, this infrastructure has only now begun to respond to the demands of the changed environment. The MPS-sponsored Workshop included representatives of academia (faculty, administrators, and students), industry, professional societies, national laboratories, government agencies, and other stakeholder institutions to examine current approaches to graduate and postdoctoral training. This document is the Summary Report of that Workshop.

As is the case for all MPS-sponsored workshops, this report is meant to assist the Directorate in its planning and interactions with the scientific community. It was understood by the participants that any changes in MPS programs and procedures will have to be discussed by the MPS Advisory Committee and possibly approved by NSF management and the National Science Board before going into effect. It was moreover the consensus of the participants that any eventual changes be gradual and be preceded by a period of experimentation in which groups in the MPS community are invited to propose innovations and changes in the conduct of graduate training.

After discussions in separate groups, the participants met in plenary session and endorsed the following recommendations.

(1) Mechanisms should be found to encourage a broadening of the training and educational experience of MPS graduate students.

(2) Mechanisms should be examined for shortening the average time to the Ph.D. degree in the MPS fields.

(3) Increased use should be made of periods of off-campus experience, such as industrial internships.

(4) Efforts should be made to decrease gradually the proportion of graduate students funded as Research Assistants and to increase gradually the proportion funded by other mechanisms, including traineeships and fellowships, as well as novel, collective modes of support.

We now discuss the findings and recommendations of the Workshop in more detail.

Findings

In the discussions at the MPS Workshop, participants identified a number of concerns about graduate training as it currently exists:

(1) The public resources available to support these activities are likely to decrease in the immediate future.

(2) The skills and knowledge acquired by new Ph.D.'s are too narrowly focused, and are not adequately applicable to the diverse business and industry environments in which most Ph.D. scientists actually work.

(3) Over the past several decades, an increasing emphasis has been placed on the research component of the graduate experience, sometimes at the expense of the best interests of the student.

(4) Diversity among students in graduate school has not been achieved to a satisfactory degree. Specifically, women, minorities and other underrepresented groups have yet to achieve parity within this population.

These findings are discussed in detail below.

(1) Resources

An overarching concern for all involved in graduate education and postdoctoral training in this country is the decline in Federal R&D budgets.

However, the participants strongly affirmed the importance of continued government support of these endeavors, even at a somewhat reduced level. Research done as part of graduate training directly affects areas important to all Americans and is justifiably supported by taxpayers. These areas include the environment, health care, safety, national security, and the technical infrastructure that is crucial for the innovation and increases in productivity that are the ultimate sources of a rising standard of living.

Thus, given both the crucial importance of graduate research and of education and the impending fiscal austerity, the workshop affirmed that it was a matter of the highest importance for the NSF/MPS to find ways to increase the return to the Nation on its investment in our fields.

(2) Breadth of Skills and Knowledge

There is no doubt that students in MPS disciplines who obtain Ph.D.'s from the research-oriented universities in this country are among the best prepared and most successful scientists in the world. The emphasis over the past half-century on physical sciences research has borne fruit, not only in spectacular advances in science, but also in the form of a myriad of new technologies and industries and in a cadre of highly trained individuals with the analytical and problem-solving skills needed to perform cutting edge work in many fields.

Often, however, these students are unaware not only of the options available to them outside of academia, but also of the applicability of the skills they have acquired through their graduate education to fields other than the one they have "trained" to enter. Moreover, students are finding that the jobs they have trained for are not as abundant as in the past in a number of the MPS disciplines.

On one hand, students are becoming increasingly specialized and compartmentalized in their educational and research pursuits. On the other hand, they are not usually encouraged to acquire the particular skills (interpersonal communication, management, or business-oriented skills) that would help them succeed in careers outside their field of preparation.

(3) The Balance between Education and Research

Many of these trends have been exacerbated by the funding process used at NSF and in other Federal agencies. Since the main criterion for judging grant applications has traditionally been the quality of the research to be performed, along with the success of past research, this is necessarily where the attention of grant applicants must be focused. Not only does this affect the principal investigators, who may believe they are expected to give lower priority to other aspects of the education of their students in order to keep the funding pipeline open, but it affects graduate and postdoctoral students themselves, who perform most of the labor involved in such research and who are often effectively discouraged from spending time on other educational pursuits not directly involved in their advisor's research project.

The current funding mechanism (where graduate students are supported primarily by Research Assistantships) also has the effect of allowing a lengthening of the time to obtain a Ph.D. Successful researchers are understandably unwilling to lose graduate stu-

dents when they have finally become highly productive, and these students may, in turn, prefer the protected, known world of the university over a usually unknown "outside" world. In neither case does the proposal and grant process take time to Ph.D. into account.

The Workshop participants also noted that a "Ph.D. or nothing" atmosphere has developed, so that the doctoral degree is often considered a minimum requirement for meaningful employment in the MPS fields. In addition, the perception of the master's degree in MPS fields as a second-rate achievement probably deters many students from entering these fields.

(4) Diversity of the Graduate Student Population

The limited involvement of women, minorities, and other underrepresented groups in mathematical and physical sciences is a long-standing phenomenon. While the Workshop participants recognized that much progress has been made to include these groups in the graduate experience, much work remains to be done. Specifically, it was noted that colleges and universities are increasingly able to attract these students into the "pipeline," but are less successful in shepherding them into and through the graduate and postdoctoral stages.

The mix of foreign and U.S. students going to graduate school was also a concern. While the scientific achievements and contributions to the country of both groups are strong, there has been a noticeable decline in the fraction of U.S. students participating in the graduate experience. This trend, coupled with the dwindling availability of resources for the support of all graduate education, has disturbing implications for the long-term health of the U.S. graduate programs in the MPS disciplines.

Recommendations

The participants at the Workshop were divided into four groups to discuss issues in particular areas of concern with respect to the graduate experience: career issues, support mode issues, educational issues, and demographic issues. Although these groups were charged with examining supposedly different aspects of the problem, a final presentation of the recommendations from each group showed a high degree of uniformity about what are the key issues and widespread consensus on recommendations.

Each general recommendation is listed below, followed by a brief supporting discussion.

(1) There should be a move to broaden the intellectual content and increase the diversity of skills acquired during Ph.D. training.

The Workshop participants noted that a more diverse mix of skills and abilities would better enable new Ph.D.'s to take advantage of the changing career market. This diversity could be fostered through encouraging the reinstatement or reinvigoration of breadth requirements, such as "minors." In these programs, schools could offer courses designed to foster interdisciplinary training or facilitate experiences that provide preparation for specific, nonacademic technical careers.

Another way to adapt graduate training to fit current requirements would be the development of professional-level master's programs in MPS disciplines, which Workshop participants likened to professional engineering degrees or the MBA. Such programs could well be linked to specific industrial or commercial career paths and would thus require significant participation from stakeholders in these sectors.

Finally, in an effort to increase the ability of MPS graduate students to choose a broader range of careers, the participants stressed that the education of these students should involve more attention to the development of "soft skills," such as ethics, business, and financial skills, and most of all communications skills, such as writing, presenting, and listening.

(2) Mechanisms for shortening the average time to Ph.D. should be examined.

The Workshop participants noted that the average time required for the completion of doctoral study has increased during recent decades. This was also a finding of the recent COSEPUP report on graduate education. Although this observation at the Workshop was based mostly on anecdotal evidence and the time-to-degree constraint would naturally differ from field to field (and even from school to school), this was nonetheless identified as a general trend.

The concern over the time required for completion of degrees centered both on the welfare of the student and on the additional cost to the Nation of long, publicly supported stays in graduate school. While these long stays may not pose a problem to those students pursuing positions in academia, students attempting to enter commercial or other sectors often find themselves at a disadvantage to those without Ph.D.'s but with a number of years of practical, on-the-job experience.

The Workshop participants did not agree to recommend that time constraints be placed on the completion of doctoral degrees across the board because longer periods of study

and research appear to be necessary in some fields. Rather, they suggested that NSF examine "best practice" data from programs around the country and encourage the shortening of time-to-degree periods where feasible.

(3) Increased use of off-campus internships and other real-world experiences.

In the interest of producing more broadly educated students with more wide-ranging career expectations and capabilities, the participants recommended the incorporation of an option for some sort of internship, or real-world work experience, into the traditional education of graduate students.

Particularly relevant to this recommendation is the success of the NSF "GOALI" program (Grant Opportunities for Academic Liaison with Industry), as well as government laboratory exchange programs, which have enabled students to gain firsthand knowledge of the culture, environment, and intellectual challenges present beyond academia. These programs have been particularly useful within the framework of the undergraduate engineering experience, but the participants believe they are applicable to the broader spectrum of MPS disciplines and to Ph.D.-level training.

To facilitate the development of these programs, the participants recognized that a significant commitment on the part of both industry officials and the university research community must be obtained. To this end, NSF should be encouraged to experiment with awards to grant applicants who propose such arrangements in a realistic and effective fashion.

(4) Gradual shift in graduate student support mechanisms.

Currently, the bulk of graduate student support provided by the Foundation is in the form of awards to individual investigators, who use these funds in part to support graduate students. Many participants agreed that this often has had the unintended consequence of limiting the areas in which students take courses and acquire experience.

The Workshop recommended that MPS experiment with means to increase gradually the fraction of graduate students supported on fellowships and traineeships. Further, NSF should encourage members of the MPS community in academia to propose new institutional, "thematic" funding mechanisms for graduate student training and support that would involve collective responsibility for groups of students.

Funds could be awarded to entire departments, to combinations of departments, or to theme-oriented entities that would allocate resources to students themselves. This would have the effect of allowing departments, or other groups, to take greater owner-

ship of the overall quality of graduate education. The criteria for making awards would have to guarantee that special, new efforts would be made to achieve the desired educational improvements. In addition, NSF could reward and encourage such "collective proposals" that exhibit success in the recruitment and retention of students from underrepresented groups, including women, minorities, and, where applicable, domestic students.

Conclusion

Above all, the Workshop offers these recommendations with the intention of stimulating further debate in the MPS community and experimentation by the NSF on ways and means to improve graduate education. These suggestions are not intended to be the final word on any particular issue, and the participants stressed that they did not endorse a "one size fits all" analysis or treatment. Improvements to graduate education can be structured in many ways. To be effective, most changes must come from within the universities and academic departments themselves. However, it was also the conclusion of the Workshop that NSF should play a constructive role in sponsoring experiment and change in graduate education.

As the world of science and engineering is changing, so, too, must the Foundation adapt to these changes. The workshop participants hope that their findings and recommendations will be helpful to the NSF community as a whole.

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